Studying the Effect of Orientation and Building Massing on Energy Performance, Case Study: Teba Building, IUG

Eng. Ashwak Sh. Jendia

Abstract— Achieving the optimum thermal performance of buildings is widely proposed. It determines how thermally comfortable the building is for its users, and how energy-efficient it is. It's undeniable that improving the energy efficiency of buildings is needed worldwide to be considered as part of the solution to the problems of energy use in buildings, especially in the Gaza Strip which suffers from energy deficit for many years. Accordingly, this paper aims to find out the potential of reducing building energy consumption through the better orientation of buildings and their massing. and it indicates to what extent they affect the building thermal performance. Ecotect Computer program was used to carry out the simulation and validate the result. For the orientation study, 18 angles were taken by rotating the building by 10 degrees for each case. For the massing study, changing the building rectangular shape dimensions graduating from the rectangle shape to the square, creating 3 forms other than the reference, with the same volume and area. The outcome result reveals clearly that the optimum orientation and better building massing affect the building thermal performance so positively, that reduce the energy consumption by the building. The optimum orientation was at the east-west orientation, and the best massing for this climate and orientation is the square. Therefore, the study recommends applying passive solar design strategies, especially with regard to the orientation and geometric shape. Thermal simulation programs have to be used in order to evaluate the thermal performance of buildings.

Index Terms— Orientation, building massing, thermal performance, energy efficiency, Gaza strip.

I. INTRODUCTION

Energy is an important environmental parameter and its use is directly related to climate change as well as a variety of air emissions [1]. It was assessed that more than a third of the primary energy used in developed countries is used within building for heating, cooling lighting. So, achieving the optimum energy performance is a crucial factor in any building design [2]. It became clear that reducing energy consumption of buildings is essential nowadays, putting in mind the limitation of conventional energy resources worldwide and the adverse effects associated with the use of such type of energy on the environment [3]. As special, Gaza Strip suffers of energy crisis because of having no stable energy source, what makes energy and electricity failure for many months a year[4]. Energy efficient buildings has emerged as a new approach to encourage using natural resources and reduce the energy requirements to maintain indoor comfortable conditions [5]. Buildings, in this case, are designed, in a way that to ensure minimum heat gain in summer and heat loss in winter in order to reduce heating and cooling loads. Therefore, applying energy efficiency mechanisms on buildings play a major role in enhancing the energy performance and comfort conditions [6]. There are many principles that can be applied on buildings to enhance their energy performance including: building massing, orientation, glazing, shading, insulation[7]. In any building design, simple techniques can be applied such as orientation, shading, vegetation to make comfortable conditions. Appropriate orientation on a building can provide a state of comfort in the building. It helps excluding the unwanted effects of severe climate. This includes orienting the building to receive maximum solar radiation in winter, together with keeping out cold winds. And avoid solar radiation in summer together with admitting cool winds. The best orientation means receiving maximum solar radiation in winter and minimum in summer achieving indoor thermal comfort. Another main parameter in determining the energy performance of buildings is the building massing and form as it can affect the received amounts of solar radiation, the rate of air infiltration and as a result the indoor thermal conditions [8].

A. Importance of the study

The important findings it provides are considered as reference, not only for university administrators, but also for many other institutions in the term of taking advantage of other experiences. Highlighting the significance of applying appropriate passive design strategies in university building in the Gaza Strip.

B. Goals and objectives

The main goal of this study is to develop the thermal performance of the university building targeted and enhancing passive design levels in University buildings in Gaza. In order to achieve this goal, the following objectives should be fulfilled:

• To study the existing thermal situation of the building

• To find out the overall energy performance of the building and the corresponding thermal comfort of the occupants.

• To determine the appropriate technics to enhance the thermal performance and the thermal comfort.

• To use the chosen technics and measures for the assessment of university building in Gaza Strip.

II. Review of existing studies

Erdim et al. (2014) [9] Impacts of building form on energy efficient heat pump application. This study explains that the most important properties of a sustainable building is to provide thermal comfort conditions for users with a minimum heating and cooling energy consumption, illustrating that building form is one of the important design parameters affecting the heating and cooling energy consumption in the building. For this purpose, two different building forms (L and rectangular) which have the same floor area, exterior facade area, volume and optical and thermo physical properties of building envelope were examined in Ankara, Turkey by using eQUEST simulation program. The result and all calculations showed that the energy consumption of rectangular shaped building form is % 9-10 less than the energy consumption of L shaped building form, and the difference between the annual energy consumptions of L shaped building form and rectangular building forms which have the same floor area, total exterior facade area, volume, roof type and optical and thermo physical properties of building envelope are caused by having the same transparency ratio but different facade areas oriented in the same direction.

Muhaisen et al. (2013) [10]. Investigation of the Thermal Performance of Building Form in the Mediterranean Climate of the Gaza Strip. The paper examines the thermal performance of different forms of the housing units located in the Mediterranean climate of the Gaza Strip. The study is carried out using ECOTECT and IES computer programs. The results indicate significant thermal effects due to form's proportions. The study concluded that the surface to volume ratio is considered the main responsible for the thermal response in different geometric shapes. Energy consumption increases at the same rate of increasing in the surface to volume ratio (S/V) in the Mediterranean climate of the Gaza Strip. Convex shapes such as court, L and U shape can be used as more preferable options for building's arrangements than the rectangular shape of the same (S/V) ratio.

Hachem et al. (2011) [11]. Parametric investigation of geometric form effects on solar potential of housing units is a study presenting the solar potential of different shapes of two-story single family housing units, located in mid-latitude climate. Seven plan geometries were studied: square, rectangle, trapezoid, L, U, H and T shapes. The study investigates the effect of these shapes on the solar radiation incident on equatorial-facing facades and transmitted by the fenestration of such facades. The parameters include, in addition to the basic shapes and roof design, variations to the geometry of L and U shapes and variations to the roof design. The results indicate that the number of shading facades in-self shading geometries and their relative dimensions are the major parameters affecting solar incident and transmitted radiation. Judicious manipulation of unit shapes and window location can lead to optimization of solar radiation and its utilization for electricity generation and passive solar gain.

Dr. Keung (2010) [12]. Building planning and massing. This study studied massing and orientation effects on the building environmental efficiency in Singapore. The study talks mainly about achieving sustainable development by applying various techniques and ways. Studying orientation and building massing on high rise built constructions was held. Dr. Keung in his study illustrated that things like the massing and orientation of buildings are fundamental for optimizing passive design, and that these are the first steps in minimizing the building energy demand, providing natural ventilation, daylight, shade, and thermal comfort. The study focused mainly on the technics of achieving optimum massing including design smaller building footprint, providing void decks at the ground floor and minimized floor depth, and orientation issue including minimal exposed to sun facades, providing extensive overhangs like balconies, planters and shading devices [9].

Mohd et al. (2007) [13].The Effect of Geometric Shape and Building Orientation on Minimizing Solar Insolation on High-Rise Buildings in Hot Humid Climate. This study examines the effect of geometric shapes and orientatio on the total solar insolation received by high-rise buildings. Two generic building shapes (square and circular) have been studied with variations in width-to-length ratio (W/L ratio) and building orientation using the computer simulation program ECOTECT. The results revealed that the circular shape with W/L ratio 1:1 is the most optimum shape in minimizing total solar insolation. The square shape with W/L ratio 1:1 in a north-south orientation receives the lowest annual total solar insolation compared to other square shapes. This optimum shape receives the highest amount of solar insolation on the east-orientated wall, followed by the south-, west- and north-orientated walls respectively.

III. Study Tools and Assumptions

A. Simulation tools

Ecotect Analysis software is a sustainable design analysis solution with architect-designed desktop tools that help measure the impact of environmental factors on buildings. It was mainly used to carry out the study. It is distinguished by its easiness to use, comprehensive analysis capabilities that help analyzing and simulating conceptual designs, ability of studying alternatives and make decisions earlier to deliver more achievable and efficient building design [14].

B. Study Assumptions

The internal spaces HVAC system were assumed to be fully air conditioning with an efficiency of 95%, 18.0° C is being the lower band and 26.0° C is the upper one. Using of building (hours of operation) was assumed to be about 8 hours in weekdays with 90-100% of occupation and 6 hours in weekends with 10-20% of occupation. The internal heat gain from occupancy, appliances and the ventilation heat gain were considered constant. In the simulation process, external walls materials were chosen typical or close to the material used in reality. Using Ecotect, the external walls have U-values of 2.55 W/m²*K. The roof U-value is 0.50 W/m²*K, glazing U-value is 6 W/m²*K. These values were assumed to achieved the minimum requirements of the U-values as recommended by the Palestinian code for energy efficient [15].

C. Location and climate of the Gaza Strip

The Gaza Strip is a narrow-rectanglepart of the Mediterranean coastal plain locating between Egypt and Israel on Longitude 34° 26' East and Latitude 31° 10' North. It is 365 km2 area and its length is approximately 45 km [16]. It’s distinguished by rainy and mild winter, while summer is hot and dry, According to the Koppen system for climatic zoning [17]. The average daily mean temperature ranges from 25 °C in summer to 13 °C in winter. The daily relative humidity fluctuates between 65% in the daytime and 85% at night in the summer, and between 60% and 80% respectively in winter. The mean annual solar radiation is 2200 J/cm2/day. The average annual rainfall varies from 450 mm/yr in the north to 200 mm/yr in the south. Most of the rainfall occurs in the period from October to March, the rest of the year being completely dry. Precipitation patterns include thunderstorms and rain showers, but only a few days of the wet months are rainy days [16].

D. Location and adjacent of Teba building

Teba building is located within the Islamic University campus as shown in Figure [1]. IUG is located in the west of Gaza city, on a flat site with an area of approximately 80,000 sq m, Teba building is located in the south part of the university campus, adjacent to Science Building from South East and Palestine Building from the North West, open green area at the front of the building and the outer street from behind.

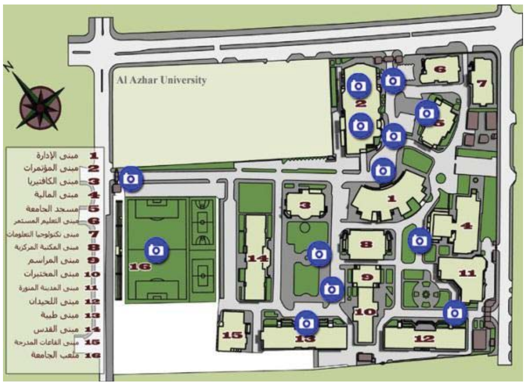


Figure 1: Islamic University Campus

IV. Case Study: Teba Building

A. The Study Parameters

The paper studied the potential of changing the building energy performance with the change in the orientation angle of the building and building massing. Achieving this, 18 angles were taken by rotating the building by 10 degrees for each case, having 18 angles together with the preference one named 0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°, 100°, 110°, 120°, 130°, 140°, 150°, 160°, 170° and 180° as shown in Figure [2]. For the building massing issue: changing the building rectangular shape dimensions graduating from the rectangle shape to the square, creating 3 forms other than the reference one named C1, C2 and C3 as shown in table [1]. The area, height and volume for all the cases were kept constant typical to the reference case.

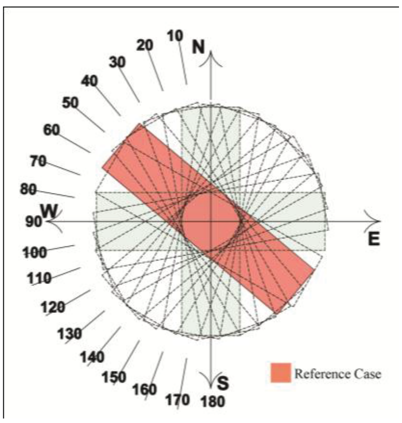
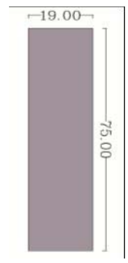
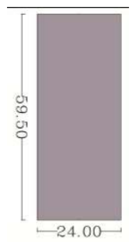
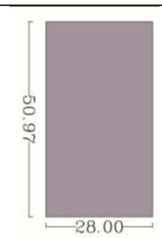
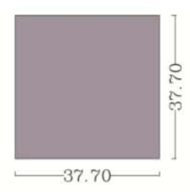


Figure 2: Rotating angles from the reference

Table 1: The different massing cases

C0	C1
	
C2	**C3**
	

B. Results

Effect of orientation

The following figures show the relation between orientation angles and heating/cooling loads. The orientation angles are shown on X axis and the heating/cooling loads on Y axis. The result illustrate the effect of changing the form's orientation on the total loads of Teba building using ECOTECT. Changing the orientation of the building is seen to have the ability to change the required energy, as it affects the amounts of solar radiation falling on the building facades and the amount of prevailing winds striking the building surfaces. As the shape of the building is rectangular, the effect of orientation in changing the total loads varies. This is due to the un equality of sides of the rectangle shape, which makes the existing orientation at (50°) and the other suggested orientations have different performances. Figure [3] shows a general trend of decreasing in the total heating loads of the building as the orientating angle changed from 50° (the reference) to 180°. The heating loads decreased by 5% because of this change. This is due to more and better exposure to sun radiation along the two long facades of the building. So, the reference case at 50° is considered as the worst case, at 160° is the best case and at 80°-150° are better cases.

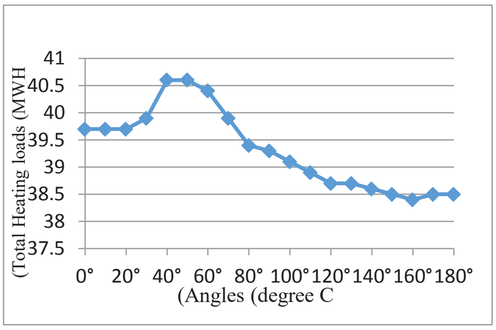


Figure 3: Effect of orientation on total heating loads

Fig [4] shows the cooling loads variation with orientation change. The chart is symmetric about its lowest point of 90° (at the east-west axis) with an increasing trend at the both sides of the 90° point to the points of 40° and 160°, and then decreasing at the two ends. So, the building at 90° is considered to be at the best case when it is on the east-west axis, at 30°,40° are the worst cases, better cases are at 60°-80° and 100°-180°. At 40°, the two long facades are exposed to the solar radiation for day long, that increases the cooling loads needed. At the contrary, the 90° point has less exposure to solar radiation and more exposure to the prevailing winds coming from the North West. The cooling load decreased by 5% when changing the reference orientation to to the east-wast one. Noticing that cooling loads are way higher than the heating ones.

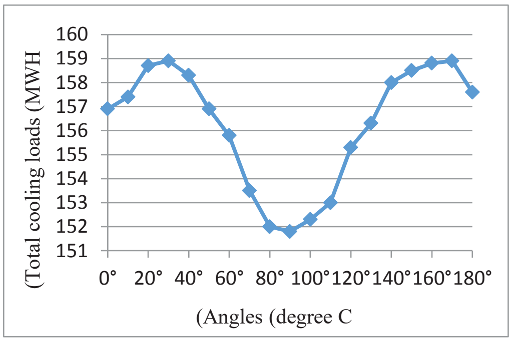


Figure 4: Effect of orientation on the total cooling loads

Fig [5] shows the total heating and cooling loads variation with the orientation change. It is noticed that this graph trend follows the trend of the cooling graph because of the very high values of cooling loads. The total heating and cooling loads decreased from 50° (the reference) to 90° (the lowest point) by 5%. Accordingly, the best case of the total heating and cooling together is at 90° at the east-west orientation, the worst case is the reference case and its adjacent points of 50°, 40° and 30°.

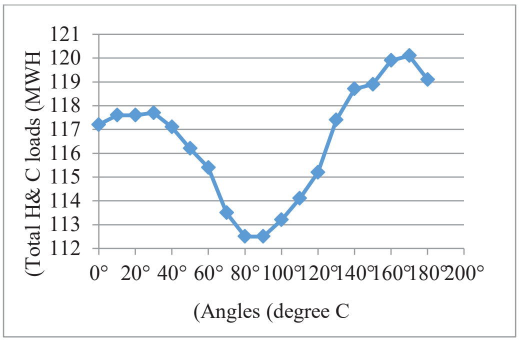
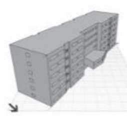


Figure 5: Effect of orientation on the total heating and cooling loads

Table 2: Best, worst and better cases of orientation depending on the total H&C loads

		
Best Case (90°)	Worst Case (40°)	Better Case (70°)

The effect of massing

The following figures show the relation between the form massing and heating/cooling loads. Form massing is shown on X axis and the heating/cooling loads are on Y axis. The result illustrates the effect of changing the building form on the total heating and cooling loads of Teba building using ECOTECT. Figures [5,6] show how the building heating and cooling loads changed with massing changes from C0 to C3. The trend of the two graphs are decreasing, the hating loads decreased by 50% and the cooling loads decreased by 24% as the massing changed from C0 the rectangle and C3 the square. This is because thinner floor plans have higher s/v ratio, so they tend to lose and get more energy to and from the outside at the contrary of square floor plans which have less s/v ratio decreasing the amount of lost/got energy to/ from the outside and the corresponding heating and cooling loads needed. C3 is considered as the best case, C0 (the reference) is the worst case, C1 and C3 are better cases.

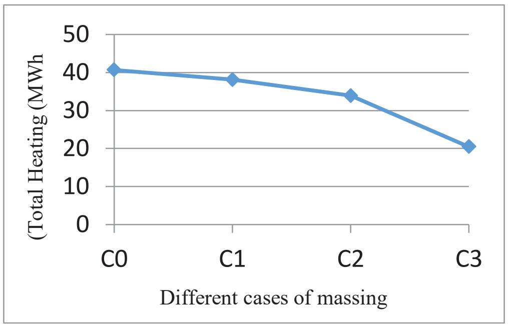


Figure 5: Effect of massing on the total heating loads

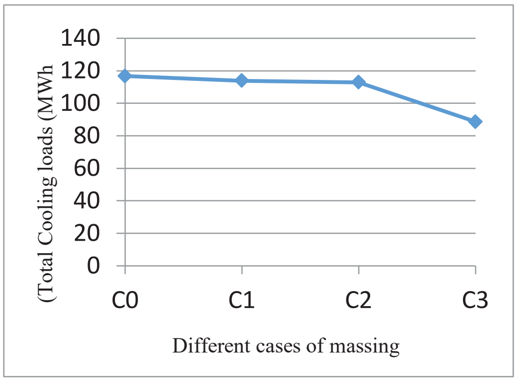


Figure 6: Effect of massing on the total cooling loads

Fig [7] shows the total heating and cooling loads change with the change of the massing. It's noticed that the graph is having a trend of decreasing following the cooling loads graph. The total heating and cooling loads are decreased by 30% when changing the massing from C0 to C3. Thus, C3 is considered as the best case, C0 is the worst.

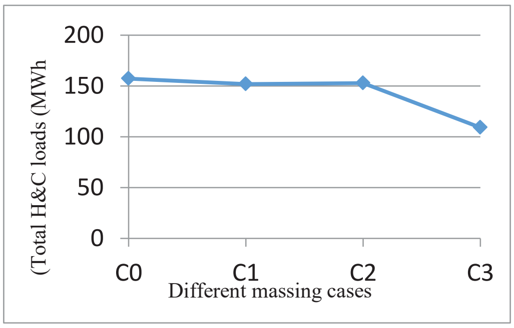
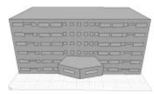


Figure 7: Effect of massing on the total Heating and Cooling loads

Table 3: Best, worst and better cases of massing depending on the total H&C loads

		
Best Case (C3)	Worst Case (C0)	Better Case (C2)

V. Conclusion

It is concluded that building massing is the most important factor affecting the building energy performance in Gaza Strip. Orientation also have the effect on the energy heating and cooling loads. The solar radiation falling on the building surfaces has a significant effect on its thermal performance, the form that has the same volume with less s/v ratio is recommended in the climate of Gaza strip. Still, rectangulare shape which is not very thin is good too. The result showed that the square shape of the building reduced the total heating loads by 50%, and the total cooling loads by 24%, and total heating and cooling loads by 30%.

Better orientation decrease the total heating loads in an amount related to building form. Best orientation was when the building long axis is East-West reducing the total heating and cooling loads by 5%. It is noticed that the percentage of enhancement is not high, this is because of the other factors that can affect this result such as glazing and building form. Coming out of this study, it is recommended to apply the best form related to the climate, study the orientation options and choose the optimum in the way that enhances the building energy performance by reducing the heating and cooling loads. More care should be given to cooling issue during summer months because the study showed high valued of cooling loads needed.

Acknowledgment

First and biggest thanks go to my father who is my very first supporter, and many thanks to Prof. Ahmed Muhaisen for his great supports and help, showing me the right way to go, and the best way to do.

References

[1] Tonima Ferdous, "Determining The Effect Of Building Geometry On Energy Use Patterns Of Office Developments." Master of

Building Science, Dept. of Architectural Eng., Ryerson Univ., Toronto, Canada, 2012.

[2] Environment, energy and economic development, Rand infrastructure, safety and environment program, RAND Corporation technical report series (2009).

[3] Papadopoulous, A. M., Giama, E., “Environmental performance evaluation of thermal insulation materials and its impact on thebuilding”, Building and Environment 42, 2178–2187, (2007).

[4] A. Muhaisen, “The energy problem in Gaza strip and its potential”, ICEEP Conference on Energy and environmental protection in sustainablw development, May 2007.

[5] Thormark, C.,“The eff ect of material choice on the total energy need and recycling potential of a building,” building and environment, 41, 1019–1026, (2006).

[6] Elias-Ozkan, S. T., Summers, F., Surmeli, N., and Yannas, S., “A Comparative Study of the Thermal Performance of Building Materials”,The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 6-8 September (2006).

[7] McGee, Caitan (2013). Passive Design. Available at <www.yourhome.gov.au/passive-design>. [Jan, 2016].

[8] Nayak, J.K. and Prajapati, J.A. (2006). Handbook on energy conscious buildings. Indian institute of technology, Bombay and Solar energy center Ministry of non-conventional energy sources, Government of India.

[9] Erdim, Banu and MANİOĞLU , Gülten (2014). Building form effects on energy efficient heat pump application for different climatic zones. ITU A|Z VOL: 11, NO: 2, 335-349 2014-2.

[10] Muhaisen, Ahmed. and Abed, Huda (2013). Investigation of the Thermal Performance of Building Form in the Mediterranean Climate of the Gaza Strip. IUG Journal of Natural and Engineering Studies. Vol.21, No.1, pp 101-122 2013, ISSN 1726-6807.

[11] Hachem, C., Athienitis, A., Fazio, P. (2011), Parametric investigation of geometric form effects on solar potential of housing units. Solar Energy, Vol. 85, No. 15, p: 1864.

[12] Keung, John (2010). Building planning and massing. The Centre for Sustainable Buildings and Construction, Building and Construction Authority. Singapore.

[13] Ahmad, Mohd. Hamdan and Ossen, Dilshan Remaz and Ling, Chia Sok (2007). The Effect of Geometric Shape and Building Orientation on Minimising Solar Insolation on High-Rise Buildings in Hot Humid Climate. Journal of Construction in Developing Countries . Vol. 12, No. 1, 2007

[14] Autodesk (2010), Autodesk Ecotect Analysis.

[15] Ministry of local government (2004). Energy efficient building code, Bailasan company, Ramallah, Palestine.

[16] Cliwasec, Climate induced changes on water and security, Department of Geography, Ludwig-Maximilians-Universitaet Muenchen (2010). available at < http://www.cliwasec.eu/projects/study_sites_details.php?studysites_id=5>.

[17] Kottek, M., Grieser, J., Beck, Ch., Rudolf, B. & Rubel, F. (2006). World Maps of Köppen-Geiger Climate classification Updated, Meteorologische Zeitschrift, 15 (3), 259-263.

Ashwaq Sh. Jendia has a Bachelor degree in Architevture from the Islamic University of Gaza, Palestine. Email: a.jendia@hotmail.com.